ON IMMERSION OBJECTIVES.

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It is a well-known fact that the thin glass plate with which microscopic objects are generally covered for protection has a great effect on the optical performance of the objective. But, it may not be generally known that this influence is a highly favorable one if properly utilized. The glass cover is a perfect means of correcting both the spherical and chromatic aberrations of the objective.

The negative flint glass lens of an objective corrects both kinds of aberrations at the same time; but, of both, it leaves the aberrations of secondary or higher order—as I have shown in previous articles on this subject. These aberrations, although much less in quantity than the primary or main aberrations, are rather new productions than remnants of the first aberrations. There are secondary means by which they may be corrected, but here, as well as by the first correction, new aberrations of a still higher order are produced. And this may be repeated *ad infinitum*.

The cover glass is free from this fault; it does its part in correcting the aberrations without producing any new defects. It is, therefore, a perfect means of correction—not because it corrects the whole amount of aberrations, for this it cannot do, but because it does its part in a perfect manner. The influence of the cover glass being thus shown, it follows that the performance of an objective will be less disturbed the greater the part the cover glass is allowed to take, by its thickness, in the correction of the objective. Hence, were the cover glass thick enough to fill the whole space between the objective and the object—which is known as "working distance"—its correcting influence would then be exerted to the greatest possible degree. The optical principle of this is: if the working distance be filled with the cover glass, the light passing through the objective is not refracted and dispersed at the front

surface, while without the cover, the refraction and dispersion of color and, consequently, the aberrations, are great.

On most of our modern wide angle objectives the refraction is greater at this surface than the sum total of the refractions at all the other surfaces of the objective. This, and the fact that the magnifying power is not affected by the influence of the cover thickness, make the importance of the cover as a means of correcting the aberrations at once clear. But, unfortunately, the working distance, which is completely filled by this ideal cover, cannot well be spared; or, at least, part of it is indispensable, as we all know too well. Now, since the correcting power of the cover is due to the refractive power of the material of which it is composed, any other body of whatever nature, but possessed of corresponding optical properties, will serve as a perfect substitute; and, therefore, a homogeneous oil may be used and thus preserve the longest possible working distance while the refraction at the front surface, and all its disturbing consequences, are completely neutralized.

In this we have the principle of the so-called "homogeneous immersion." The object is mounted in a homogeneous medium and covered with a glass circle; the remaining part of the working distance is then filled with homogeneous fluid; it makes no difference whether the cover is very thick or extremely thin; the variation is always balanced by a proportionate amount of the fluid. Although, from an optical standpoint, this form of immersion seems all that is to be desired, its practical application is strongly influenced by the many inconveniences of the different kinds of homogeneous media known at present; and, therefore, for practical work, a fluid that has the least of these peculiar inconveniences may be preferable even should its optical qualities not so completely fulfill the conditions described.

Such a fluid is water. It was for many years past the only immersion medium in general use. The refractive power of water being much lower than that of glass or homogeneous oil, it will, if put in place of those substances, exert a correspondingly smaller influence in correcting the aberrations. But, on the other hand, while the use of the homogeneous medium permits the preservation of the full working distance without any loss in correction, this loss,

if water be employed, can, in a great degree, be regained if so much of the working distance as can be spared is sacrificed and the space filled with glass. This can best be done by adding to the thickness of the front lens, so much that only just enough of the working distance is left as is practicable, and then fill the comparatively small immersion space with water. Indeed, by a skillful balancing of the interfering conditions, the difference between the adaptation of water and homogeneous oil can be reduced to a minimum, and yet the working distance be as long as is practically required.

The high optical superiority of the modern homogeneous immersion objectives over the old water immersion may seem to disprove this theory. But I do not hesitate to claim, right here, that the wonderful performance of these objectives is due, in a comparatively small degree only, to the homogeneous immersion; it is due, in a far greater degree, to the increase of the number of lenses and, consequently, the number of refracting surfaces. We remember that at the same time as the homogeneous immersion the four-system principle was introduced. Probably a more important advantage of the homogeneous over the water immersion, than that of the higher corrective power, may be found in the fact that adjustment for cover thickness is unnecessary. But even this merit is doubted by many first-class authorities on the manipulation of the microscope, and the demand for adjustable, homogeneous objectives is on the increase.

Under such circumstances, weighing its merits and its faults, it must be admitted that the practical advantages of the homogeneous immersion principle are at least doubtful. This cannot be said of the four-system principle. It is unnecessary to enter into a thorough theoretical investigation of this matter. It may suffice to call to mind the fact that the aberrations of higher order are inversely proportional to the number of refracting surfaces. The objection that there is also a corresponding loss of light, although practically true, is of no consequence whatever, as is sufficiently demonstrated by the extensive experience in the use of this class of objectives.

Summing up, we come to the conclusion that the future, high power objectives will be the four-system water immersion. Or, the immersion will be done away with altogether as an incurable inconvenience, and the four-system dry working objective will be used.